Measurement of Longitudinal Short Period Characteristics

Damping and frequency (or period) of the airplane short period mode of motion have been shown to have a profound effect on overall longitudinal flying qualities. However, it is most appropriate to investigate the characteristics of this motion during maneuvering tasks because of the effect of these characteristics on the response of the airplane to external perturbations or longitudinal control inputs. It is necessary to discuss the effect of varying short period characteristics by varying only one parameter at a time. For the discussion of the effect of varying short period frequency it is assumed that the damping ratio of the short period motion is fixed at an acceptable level.

Short Period Frequency. The parameter, $\omega_{d_{sp}}$ is the damped frequency of the second-order, short period mode of motion. If it is a real, positive number, it is directly related to the physical frequency (or quickness) with which the airplane responds to an elevator input or an external disturbance. In visual flight, the pilot notes this frequency of response by reference to the pitch attitude of the airplane, the normal accelerometer, or angle of attack indicator. The pilot is also sensitive to this frequency of response through the normal acceleration he feels. When flying by reference to instruments, the normal accelerometer, angle of attack indicator, and "normal acceleration feel" provide cues of the response frequency of the airplane. Obviously, the damped frequency of the short period mode of motion has a very large influence on the pilot's opinion of the longitudinal flying qualities of the airplane. However, the damped frequency is dependent on damping ratio as well as the undamped natural frequency. Therefore, airplane short period flying qualities requirements and data are usually presented in terms of the undamped natural frequency, $\omega_{n_{sp}}$ and damping ration ζ_{sp} . Although the undamped natural frequency might seem to be of academic interest only (at first glance), it will now be shown that it is actually a useful means of describing the longitudinal maneuvering behavior of the airplane as the pilot sees it.

With satisfactory damping of the short period mode, the following rationalizations may be made concerning the effect of various short period natural frequencies on longitudinal flying qualities.

1. For "low" $\omega_{n_{sp}}$ values - the pilot find that the airplane tends to "dig-in" during maneuvering. This characteristic is explained by the fact that the airplane does not respond quickly enough initially to the pilot's control input. The pilot therefore tends to put in too large an input when attempting to make a rapid flight path change, such as a sharp pull-up or rapid turn entry. The large input yields the desired initial response; however, the pilot soon finds that the final response, once it develops, is more than he wanted. Thus it is the initial response which the pilot finds lacking when attempting vigorous maneuvering tasks at low short period natural frequencies. If the airplane is always maneuvered slowly and smoothly, the pilot probably does not object to the slow initial response. (The large transport or passenger airplane, with large moments of inertia in pitch, are characterized by low short period natural frequencies. Since these airplanes do not have to be maneuvered extensively in their missions, however, the pilot may feel the response characteristics are perfectly satisfactory.) Trimmability may be impaired somewhat if $\omega_{n_{sp}}$ is too low. This is due to the fact that every trim input the pilot makes requires a relatively long time interval to take effect. Thus the pilot thinks he is in trim initially, but finds later that a little further trim correction is necessary. The pilot does not have a good, firm knowledge of when the trim setting is exactly correct.

2. If the short period undamped natural frequency is "medium" to "high", the response of the airplane to longitudinal control inputs is generally satisfactory for maneuvering tasks. The airplane is quick responding longitudinally and the pilot will generally feel very confident during

gunsight tracking or bombing deliveries. During vigorous maneuvering, the pilot has a strong, positive feeling that the normal acceleration response will be exactly what was desired when the elevator input was made. This "predictability factor" is important to the pilot. Additionally, the medium to high short period frequency enhances longitudinal trimmability. With the medium to high frequency, every correction made during the task of trimming takes less time and comes to a completion quicker. This gives the pilot the feeling that he knows exactly what trim correction is necessary. In other words, the airplane's longitudinal trim point is well defined and corrections to the trim point are made quickly.

3. For "very high" $\omega_{n_{sp}}$ values - the pilot may complain that the initial response of the airplane is too fast or too quick. This is due to the fact that the high natural frequency makes the airplane too sensitive and responsive to very small longitudinal control inputs. During precise tracking maneuvers, the pilot tends to "bobble" the nose position of the airplane. This may impair precise placement of ordnance during certain maneuvering tasks required in mission accomplishment. If the airplane is flown in turbulence, it may respond so abruptly through angle of attack and normal acceleration changes that the pilot is subjected to an uncomfortable, teeth-rattling ride. Flying qualities investigations have shown that increasing "stick force per g" gradients tend to attenuate the sensitivity and "bobbling" tendencies associated with high short period natural frequencies. The higher F_s/n gradients merely require the pilot to use larger force inputs during any maneuver, which tends to decrease the initial abruptness and sensitivity experienced with lighter F_s/n gradients. However, this type of compromise is never completely satisfactory since steady longitudinal control forces in pull-ups and turns may become excessive. If the short period natural frequency is very high, even the best compromise value of F_s/n cannot make the maneuvering characteristics acceptable.

Short Period Damping. The parameter, ζ_{sp} , is the damping ratio of the short period mode of motion. Its value strongly affects the time or dynamic response of the airplane to a longitudinal control input or an external distrubance. Pilots are very sensitive to this parameter. It may be detected in visual flight by observing the pitch attitude of the airplane as the airplane responds to an elevator input. The pilot notes the peak value and oscillatory nature of the response. The damping ratio can be detected in instrument flight by reference to the normal accelerometer or angle of attack indicator.

Short period damping ratio has a direct effect on piloting technique and the pilot's opinion of the longitudinal flying qualities of the airplane, particularly during maneuvering tasks. At a constant short period undamped natural frequency of reasonable value, the pilot's description of the airplane can be varied from "over-responsive" to "sluggish" merely by changing the damping ratio. Assuming a satisfactory $\omega_{n_{sp}}$, the following rationalizations may be made concerning the effect of various short period damping ratios on longitudinal flying qualities.

1. For very low damping ratios - the airplane short period motion is very easily excited by pilot inputs or external disturbances. Once excited, the motion (pitch attitude, normal acceleration, and angle of attack oscillations) tends to persist for a relatively long period of time. When the pilot attempts to maneuver the airplane vigorously, he finds the longitudinal response is oscillatory and the resulting oscillations in angle of attack and normal acceleration disconcerning and uncomfortable. Thus, the pilot will probably switch to cautious longitudinal control inputs in an attempt to keep from exciting the short period motion. Longitudinal control forces required in maneuvering will probably feel lighter to the pilot than the actual force gradient. This is because the initial response of the airplane is quicker than the pilot thinks it should be, therefore, the pilot thinks he applied more force than he should have applied.

2. For low short period damping ratios - the airplane short period motion is still quite apparent to the pilot, however, it is very noticeably damped. The pilot may still use somewhat cautious control inputs because a noticeable overshoot in desired angle of attack and normal acceleration occurs when large, abrupt inputs are made. However, the pilot will feel more comfortable in maneuvering vigorously than he would with the very low short period damping. Longitudinal control forces in maneuvering flight may still seem a bit light.

3. For moderate short period damping ratios - the airplane short period motion is natural and predictable. The response of the airplane to a longitudinal control input is such that the pilot feels that he can change angle of attack, pitch attitude, and normal acceleration to whatever values he desires. In addition, the pilot feels that he can make these changes precisely without any overshoot or undershoot in amplitude. Longitudinal control forces during maneuvering flight feel normal. The pilot thus feels very secure in maneuvering the airplane vigorously; maneuvering tasks required in mission accomplishment are performed without undue pilot effort.

4. The fairly heavy and heavy short period damping, the airplane short period motion is not evident to the pilot. The response of the airplane to longitudinal control input approaches a steady state value with a minute overshoot or it approaches the steady state purely asymptotically. As the short period damping ratio increases, the airplane response becomes slower and slower; the pilot resorts to "forcing" the initial response by applying large elevator inputs to get the response started. For this situation, the pilot describes the airplane as "sluggish" during maneuvering, and because he resorted to using large initial elevator inputs, longitudinal maneuvering control forces feel higher than normal.